

WHAT IS CLAIMED IS:

1. An apparatus for the continuous determination of a parameter characterizing a patient's left ventricular pumping action, comprising

- a first input channel for continuous recording of a variable physiological first reading directly dependent on the left ventricular pumping action, and
- an evaluation unit for calculating said parameter characterizing the left ventricular pumping action,

wherein said apparatus also comprises a second input channel for continuous recording of a variable physiological second reading which at least approximately indicates the patient's intrathoracic pressure (ITP) or is dependent on same,

wherein said evaluation unit is programmed for calculating the parameter characterizing the patient's left ventricular pumping action from said first reading, using a corrective function based on said second reading.

2. The apparatus according to claim 1, wherein said first input channel is configured for reading a pressure transducer signal, wherein said first reading at least approximately corresponds to the patient's aortic pressure, and wherein programming of the evaluation unit allows the calculation of said parameter characterizing the patient's left ventricular pumping action by means of a pulse contour analysis.

3. The apparatus according to claim 2, wherein said first reading which at least approximately corresponds to the aortic pressure is an arterial pressure.

4. The apparatus according to claim 3, wherein said arterial pressure is a pressure measured close to the aorta.

5. The apparatus according to claim 2, wherein said pulse contour analysis is based on a non-linear windkessel model.

6. The apparatus according to claim 2, wherein the corrective function has the form of

$$P_{transmural} = Pao - f(C) * P_{IT}$$

wherein

Pao is said first reading which at least approximately corresponds to the aortic pressure,

P_{IT} is said second reading which at least approximately expresses the intrathoracic pressure (ITP), and f(C) is a function which depends on the compliance (C) of the arterial system or the aorta and which increases monotonically as the compliance increases and may assume values between 0 and 1, and wherein the transmural pressure (P_{transmural}) is the determining pressure in the pulse contour analysis.

7. The apparatus according to claim 6, wherein said function f(C) has the formula

$$f(C) = 1 - \exp(-a * C)$$

wherein $\exp(-a * C)$ is an exponential function with argument - a * C, wherein (C) is compliance of the arterial system or the aorta, and (a) is an estimated or experimentally determined constant.

8. The apparatus according to claim 7, wherein a dependence of the compliance (C) on the transmural pressure ($P_{transmural}$) is assumed and that both of these values are calculated by means of iteration.

9. The apparatus according to claim 1, wherein said second input channel is configured for reading a pressure transducer signal, and wherein said second reading at least approximately corresponds to the patient's central venous pressure (CVP).

10. The apparatus according to claim 1, wherein said parameter that characterizes the patient's left ventricular pumping action is one of a group of cardiac output, stroke volume and a parameter directly calculated from those.

11. An apparatus for the continuous determination of the cardiac volume responsiveness indicator, comprising:

a first input channel for the continuous recording of a variable physiological first reading directly dependent on a patient's left ventricular pumping action,

a second input channel for continuous recording of a variable physiological second reading at least approximately representing the patient's intrathoracic pressure (ITP),

a third input channel for continuous recording of a third reading which depends directly on the patient's state of respiration, and

an evaluation unit for calculating said cardiac volume responsiveness indicator,

wherein the evaluation unit is programmed to use said second and third readings to select a function that can be used for the patient's current state of respiration and based on this function, to calculate said volume responsiveness indicator from said first and second readings.

12. The apparatus according to claim 11, wherein said first reading is a size of the left ventricle which is determined by means selected from the group consisting of x ray densitometry, positron emission tomography, transesophageal echo cardiography, transthoracic echo cardiography and other two- or three-dimensional imaging techniques.

13. The apparatus according to claim 11, wherein said first reading which depends on the patient's left ventricular pumping function is a reading determined by a measurement selected from the group consisting of plethysmography, measuring the electric impedance, measuring the electric conductivity, ultrasound, measuring the pressure in the *Arteria pulmonalis*, and direct flow measurement.

14. The apparatus according to claim 11, wherein said first input channel (5a) is configured for reading a pressure transducer signal, and wherein said first reading at least approximately corresponds to the patient's aortic pressure.

15. The apparatus according to claim 11, wherein said evaluation unit is programmed to calculate from the temporal variability of said first reading at least one of a value selected from the group consisting of stroke volume variation (SVV), systolic pressure variation (SPV), pulse pressure variation (PPV) and a similar value.

16. The apparatus according to claim 14, wherein said evaluation unit is programmed to calculate at least one

of a value selected from the group consisting of stroke volume variation (SVV), systolic pressure variation (SPV), pulse pressure variation (PPV) and a similar value, from the first reading by means of pulse contour analysis, using a corrective function formed with the second reading.

17. The apparatus according to claim 16, wherein said corrective function has the formula:

$$P_{transmural} = P_{ao} - f(C) * P_{IT}$$

wherein P_{ao} is said first reading which at least approximately corresponds to the aortic pressure,

P_{IT} is said second reading which at least approximately expresses the intrathoracic pressure (ITP), and

$f(C)$ is a function which depends on compliance (C) of the arterial system or the aorta and which increases monotonically as the compliance increases and may assume values between 0 and 1,

and wherein transmural pressure ($P_{transmural}$) is a determining pressure in the pulse contour analysis.

18. The apparatus according to claim 17, wherein said function $f(C)$ has the formula

$$f(C) = 1 - \exp (-a * C)$$

wherein $\exp(-a * C)$ is an exponential function with argument $-a * C$, wherein (C) is compliance of the arterial system or of the aorta (2), and (a) is an estimated or experimentally determined constant.

19. The apparatus according to claim 18, wherein a dependence of the compliance (C) on transmural pressure ($P_{transmural}$) is assumed and that both of these values are calculated by means of iteration.

20. The apparatus according to claim 11, wherein selection of the function to be applied to the patient's current respiration status consists of a choice between a first function valid for the artificial respiration of the patient and a second function valid for the patient's spontaneous breathing.

21. The apparatus according to claim 20, wherein said first function valid for the artificial respiration of the patient has the formula

$$CVRI = k * (XXV / \Delta PIT)$$

and that said second function valid for the patient's spontaneous breathing has the formula

$$CVRI = l - m * (\Delta PIT / XXV)$$

wherein CVRI is the cardiac volume responsiveness indicator, XXV is one of the group of stroke volume variation (SVV), systolic pressure variation (SVP), pulse pressure variation (PPV) and a similar value describing the left ventricular pumping function, Δ PIT is the variation of said second reading which at least approximately expresses the intrathoracic pressure (ITP) during a breathing cycle, and wherein k, l and m are adaptation parameters.

22. The apparatus according to claim 21, wherein said adaptation parameters k, l and m are adaptation functions.

23. The apparatus according to claim 21, wherein said adaptation parameters k, l and m are estimated or experimentally calculated constants.

24. The apparatus according to claim 23, wherein said adaptation parameters k, l and m are selected such that both functions result in a same value in their application range when an end-diastolic volume for the patient's cardiac volume responsiveness indicator (CVRI) remains the same.

25. The apparatus according to claim 20, wherein the programming of the evaluation unit allows for determination of an onset of the patient's inhalation based on temporal variability of said third reading; and the determination whether said first function valid for the artificial respiration of the patient or said second function valid for the patient's spontaneous breathing should be used, depending on a phase shift between the onset of inhalation and the beginning of the rise of said second reading which at least approximately expresses the intrathoracic pressure (ITP), such that artificial respiration has to be assumed for a phase shift lying below a threshold value between the onset of inhalation and the beginning of the rise of said second reading, and spontaneous breathing has to be assumed for a phase shift lying above a threshold value between the onset of inhalation and the beginning of the rise of said second reading.

26. The apparatus according to claim 11, wherein said third reading at least approximately corresponds to the patient's thoracic compliance.

27. The apparatus according to claim 26, wherein said third input channel is configured for reading one of the group of a strain gauge (DMS) or a sensor measuring the impedance.

28. The apparatus according to claim 11, wherein said third reading at least approximately corresponds to one of the group of the respiration pressure and the volume flow of the patient's tidal air.

29. The apparatus according to claim 11, wherein said second input channel is configured for reading a pressure transducer signal, and wherein said second reading at least approximately corresponds to the patient's central venous pressure.

30. A method of continuous determination of a parameter characterizing a patient's left ventricular pumping action, comprising the steps of:

recording a variable physiological first reading directly dependent on the left ventricular pumping action;

continuously recording a variable physiological second reading which at least approximately indicates the patient's intrathoracic pressure (ITP) or is dependent on same; and

calculating said parameter characterizing the left ventricular pumping action from said first reading, using a corrective function based on said second reading.

31. The method of claim 30, wherein said first reading is taken from a pressure transducer signal which at least approximately corresponds to the patient's aortic pressure, and wherein said parameter characterizing the patient's left ventricular pumping action is calculated by means of a pulse contour analysis.

32. The method according to claim 31, wherein said first reading which at least approximately corresponds to the aortic pressure is an arterial pressure.

33. The method according to claim 32, wherein said arterial pressure is a pressure measured close to the aorta.

34. The method according to claim 31, wherein said pulse contour analysis is based on a non-linear wind kessel model.

35. The method according to claim 31, wherein the corrective function has the form of

$$P_{transmural} = Pao - f(C) * P_{IT}$$

wherein

Pao is said first reading which at least approximately corresponds to the aortic pressure,

P_{IT} is said second reading which at least approximately expresses the intrathoracic pressure (ITP), and

f(C) is a function which depends on compliance (C) of the arterial system or the aorta and which increases monotonically as the compliance increases and may assume values between 0 and 1,

and wherein transmural pressure (P_{transmural}) is the determining pressure in the pulse contour analysis.

36. The method according to claim 35, wherein said function f(C) has the formula

$$f(C) = 1 - \exp(-a * C)$$

wherein $\exp(-a * C)$ is the exponential function with the argument $-a * C$, wherein (C) is the compliance of the arterial system or the aorta, and (a) is an estimated or experimentally determined constant.

37. The method according to claim 36, wherein a dependence of the compliance (C) on the transmural pressure ($P_{transmural}$) is assumed, and both of these values are calculated by means of iteration.

38. The method according to claim 30, wherein said second reading is taken from a pressure transducer signal, and wherein said second reading at least approximately corresponds to the patient's central venous pressure (CVP).

39. The method according to claim 30, wherein said parameter that characterizes the patient's left ventricular pumping action is selected from the group consisting of cardiac output, stroke volume and a parameter directly calculated from those.

40. A method of continuous determination of the cardiac volume responsiveness indicator, comprising the steps of

- recording a variable physiological first reading directly dependent on the patient's left ventricular pumping action,
- recording a variable physiological second reading at least approximately representing the patient's intrathoracic pressure (ITP),
- recording a third reading which depends directly on the patient's state of respiration,
- using said second and third readings to select a function that can be used for the patient's current state of respiration, and, based on this function,
- calculating said cardiac volume responsiveness indicator from said first and second readings.

41. The method according to claim 40, wherein said first reading is the size of the left ventricle which is determined by means of a method selected from the group consisting of X ray densitometry, positron emission

tomography, transesophageal echo cardiography, transthoracic echo cardiography and other two- or three-dimensional imaging techniques.

42. The method according to claim 40, wherein said first reading which depends on the patient's left ventricular pumping function is a reading determined by a measurement selected from the group consisting of plethysmography, measuring electric impedance, measuring electric conductivity, ultrasound, measuring pressure in *Arteria pulmonalis*, and direct flow measurement.

43. The method according to claim 40, wherein said first reading is taken from a pressure transducer signal, and wherein said first reading at least approximately corresponds to the patient's aortic pressure.

44. The method according to claim 40, wherein from the temporal variability of said first reading at least one of the group of stroke volume variation (SVV), systolic pressure variation (SPV), pulse pressure variation (PPV) and a similar value is calculated.

45. The method according to claim 44, wherein said evaluation one of the group of stroke volume variation (SVV), systolic pressure variation (SPV), pulse pressure variation (PPV) and a similar value, is calculated from said first reading by means of pulse contour analysis, using a corrective function formed with the second reading.

46. The method according to claim 45, wherein said corrective function has the formula

$$P_{transmural} = P_{ao} - f(C) * P_{IT}$$

wherein

P_{ao} is said first reading which at least approximately corresponds to the aortic pressure,

P_{IT} is said second reading which at least approximately expresses the intrathoracic pressure (ITP), and

$f(C)$ is a function which depends on compliance (C) of the arterial system or the aorta and which increases monotonically as the compliance increases and may assume values between 0 and 1,

and wherein the transmural pressure ($P_{transmural}$) is the determining pressure in the pulse contour analysis.

47. The method according to claim 46, wherein said function $f(C)$ has the formula

$$f(C) = 1 - \exp(-a * C)$$

wherein $\exp(-a * C)$ is the exponential function with argument $-a * C$, wherein (C) is compliance of the arterial system or of the aorta (2), and (a) is an estimated or experimentally determined constant.

48. The method according to claim 47, wherein a dependence of the compliance (C) on the transmural pressure ($P_{transmural}$) is assumed and that both of these values are calculated by means of iteration.

49. The method according to claim 40, wherein selection of the function to be applied to the patient's current respiration status consists of a choice between a first function valid for the artificial respiration of the patient and a second function valid for the patient's spontaneous breathing.

50. The method according to claim 49, wherein said first function valid for the artificial respiration of the patient has the formula

$$CVRI = k * (XXV / \Delta PIT)$$

and that said second function valid for the patient's spontaneous breathing has the formula

$$CVRI = l - m * (\Delta PIT / XXV)$$

wherein CVRI is the cardiac volume responsiveness indicator, XXV is selected from the group consisting of stroke volume variation (SVV), systolic pressure variation (SVP), pulse pressure variation (PPV) and a similar value describing the left ventricular pumping function, Δ PIT is the variation of said second reading which at least approximately expresses the intrathoracic pressure (ITP) during a breathing cycle, and wherein k, l and m are adaptation parameters.

51. The method according to claim 50, wherein said adaptation parameters k, l and m are adaptation functions.

52. The method according to claim 50, wherein said adaptation parameters k, l and m are estimated or experimentally calculated constants.

53. The method according to claim 52, wherein said adaptation parameters k , l and m are selected such that both functions result in a same value in their application range when an end-diastolic volume for the patient's cardiac volume responsiveness indicator (CVRI) remains the same.

54. The method according to claim 49, wherein the onset of the patient's inhalation is determined based on the temporal variability of said third reading; and it is determined whether said first function valid for the artificial respiration of the patient or said second function valid for the patient's spontaneous breathing should be used, depending on the phase shift between the onset of inhalation and the beginning of the rise of said second reading which at least approximately expresses the intrathoracic pressure (ITP), such that artificial respiration has to be assumed for a phase shift lying below a threshold value between the onset of inhalation and the beginning of the rise of said second reading, and spontaneous breathing has to be assumed for a phase shift lying above a threshold value between the onset of inhalation and the beginning of the rise of said second reading.

55. The method according to claim 40, wherein said third reading at least approximately corresponds to the patient's thoracic compliance.

56. The method according to claim 55, wherein said third reading is taken from a signal of a strain gauge (DMS) or a sensor measuring the impedance.

57. The method according to claim 56, wherein said third reading at least approximately corresponds to one of the respiration pressure and the volume flow of the patient's tidal air.

58. The method according to claim 40, wherein said second reading is taken from a pressure transducer signal, and wherein said second reading at least approximately corresponds to the patient's central venous pressure.